UNPUBLISHED PRELIMINARY DATA

THE UNIVERSITY OF MICHIGAN U, Ann Arbor
THE RADIATION LABORATORY
DEPARTMENT OF ELECTRICAL ENGINEERING 572600S Radiation Lab.

ANN ARBOR NORMANDY 3-1511
EXTENSION 3037

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ANN ARBOR, MICHIGAN
48104

6p

(Rept. 5780-1-T) N64 13336 *
20 November 1963 6p
Code 1
(NASA CR 55191) OTS:

National Aeronautics and Space Administration
Washington 25, D.C.

Attention: T.L.K. Smull, Director
Grants and Research Contracts
Office of Space Sciences

Subject: First Semi-Annual Progress Report, 1 May - 1 Nov. 1963

Reporting Period: 1 May to 1 November 1963

Contract Title: T Analytical Studies of Relationships between Far-Field Radiation Patterns and Near-Field Current Distributions and Surface Configurations, including Consideration of the Effects of Small-Vehicle (Few Wavelengths) on Antenna Performance

Contract No. (NASA Grant NsG 444)

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OTS PRICE

XEROX $ 1.10 ph
MICROFILM $ 0.80 mf.

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Semi-Annual Report on NASA Research Grant NsG-444

One of the main problems in the design of antennas for space vehicle applications is to obtain sensibly omnidirectional coverage. If we assume that the vehicle is some body of revolution, for example, a combination of a cone and a cylinder or even an ellipsoid of large length-to-width ratio, the creation of good fore-and-aft coverage is relatively easy to achieve and requires only a slot of dimensions small in comparison with the wavelength. Circumferentially, however, a similar degree of coverage is difficult whenever the radius of the surface is comparable to or larger than the wavelength.

In the past most attempts to realize an omnidirectional pattern have employed a series of conventional radiators spaced around the circumference and separated by a half wavelength or so. In the flush-mounted case where slots are used, the structure of the vehicle is necessarily weakened. This is even more true if the slots are fed from a single feed on the axis of the vehicle (as in a spherical slot antenna), and in addition such a system is extremely wasteful as regards space. Other methods of feeding using, for example, waveguides just below the skin, may become complex if several sections are required and may involve delicate tuning and/or be limited in bandwidth. Finally, there is the objection that all multi-radiator systems lead to a pattern with as many minima as there are radiators, and the avoiding of (deep) minima is essential. It is therefore clear that there is ample scope for the invention and design of alternative ways of radi-

ating power from a curved surface, with particular reference to the problems posed by the requirement of omnidirectionality, and so far the main effort under the present grant has been devoted to this study.

Without loss of generality it can be assumed that the surface from which the power is to be radiated is an infinitely-long circular cylinder of radius a. The material of which the cylinder is constructed is presumed to be at our disposal, although prime consideration has been given to the metallic case. The task is to set up on the surface of the cylinder in the simplest manner possible the field distribution necessary to achieve a specified far field pattern $P(\theta)$ in the circumferential direction.

Given the pattern factor $P(\theta)$ throughout the whose range $0 \leq \theta < 2\pi$, it is a simple matter to determine the necessary surface distribution, but not quite so obvious is the numerical relationship between errors in the desired $P(\theta)$ and corresponding variations at the surface. An analysis has shown the manner in which these depend on the Legendre function decomposition of $P(\theta)$ and the radius of the surface in comparison with the wavelength. If $P(\theta)$ is given only in a restricted range $0 \leq \theta \leq \theta_o$, say, where $\theta_o > 0$, and is unknown outside this range then, mathematically at least, the entire surface distribution can be determined and, from this, the continuation of the far field pattern for $\theta_o < \theta < 2\pi$. The reason for this unusual result is the mathematical analyticity of $P(\theta)$, which enables all derivatives of $P(\theta)$ to be obtained providing only that $\theta_o \neq 0$. Practically, however, it is clear that a knowledge of $P(\theta)$ in a restricted range will specify only

those Legendre components in the angular spectrum up to order n, where $n \sim 1/\theta_o$, and the consequences of so limiting the data on $P(\theta)$ have been examined.

To synthesize a given radiation pattern which is known for $0 \leqslant \theta < 2\pi$, two theoretical methods have been investigated. The first of these assumes two radiating slots diametrically opposed on the surface, and for a pre-assigned maximum value for the quality factor (or super-directive ratio) the best mean-square fit to the prescribed $P(\theta)$ has been obtained. The calculations involved in this optimization procedure are well suited to a computer. However, for the analysis to be valid it is necessary that the radius be much greater than the wavelength and the angular width small, and even then it may well be that the closeness of fit to $P(\theta)$ could only be made satisfactory by increasing the number of slots. Paralleling this effort, an exact analysis of the problem for a cylinder of arbitrary radius and a slot of arbitrary width has been attempted, but the mathematical difficulties appear too great to achieve any practically useful results. On the other hand, an extension of the original analysis to a non-metallic surface has been achieved.

An alternative approach to the problem which is presently under consideration is as follows: given a cylinder whose surface impedance is allowed to vary in the θ direction, and which has n equally spaced line sources around its circumference, to determine the impedance necessary for a best fit to an omnidirectional radiation pattern. Clearly the impedance must be a periodic function of angle with period $2\pi/N$, and will depend on the mode(s) launched by the sources,

but if the sources could be designed to launch waves only in one direction (thereby avoiding standing waves on the surface) a good fit to a uniform $P(\theta)$ may be possible.

It will be observed that none of these methods have got away from the practical difficulty associated with many radiators around the circumference, and are at best only ways of getting a closer fit to a prescribed pattern with a given number of them. Any one will radiate a certain amount of energy directly into space and put the remainder into surface (or creeping) waves of one or more modes. The latter radiate in the tangential direction as they travel around the surface, and their strength is thereby proportionately reduced. Obviously, the pattern associated with the energy directly radiated by the source cannot be isotropic if for no other reason than the shadowing produced by the surface. A maximum coupling into creeping waves would therefore seem desirable, and the variation of these in the θ direction depends on the order n of the modes. The lowest order (n = 0) would therefore appear appropriate for creating a uniform far field pattern, but since the wave radiates it must also decay, leading to a tapering of the pattern. For a metallic surface, the rate of radiation and decay is determined by the radius in terms of the wavelength, but for surfaces other than metallic, the rate of decay can be changed. To reduce it, however, would reduce the radiation and would not be desirable in a radiating system.

To break the deadlock, several fairly exotic systems are presently under investigation for replenishing the energy in the creeping wave and thereby extending the angular range over which the resulting pattern is sensibly uniform. One of

these employs a wire which lies above the surface in the circumferential direction at a height which varies as a function of θ in order to vary the coupling of energy into the creeping wave. Modifications to the coupling rate can be obtained by partially coating the wire and/or surface beneath it. An alternative to this scheme uses a single line source parallel to the axis of the cylinder, but placed inside a coating whose thickness is a function of θ.

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